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Geomorphological features and processes in the Sierra de Famatina, La Rioja

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ABSTRACT

The Sierra de Famatina is considered the highest elevation outside the Argentine Andes Cordillera, being the General Belgrano hill, 6097 masl, the main height. This altitudinal situation favored the development of glaciers during the cold events of the cyclical Quaternary climatic fluctuations, giving shape to a territory with very complex morphologies. The aim of this contribution is to describe the current and past geomorphological processes in the vicinity of the highest sector of the Sierra de Famatina through different forms of the landscape, which put together allow the recognition of the geomorphological evolution of the region. At present, extreme weather lead to periglacial conditions above 4000 m and glacial above 6000 m, generating ice and snow patches almost without movements in flat to flat-concave sections of the watersheds, and rock glaciers, gelifluction lobes and earth hummocks in cirques, troughs and walls of valleys. Depending on the features of glacial accumulation, three cold events can be recognized, the youngest one (MIS2) with limited distribution, is restricted to the heads of troughs and cirques, from whose deposits the rock glaciers develop. The second one, observed near Puesto Tres Piedras, is represented by moraine-shaped glacier deposits above 3000 m height, and would belong to the Middle-Late Pleistocene. The oldest glacier deposits, early-middle Pleistocene, are in higher topographies. Below 3000 m, valleys are rocky and steep-sided, with permanent courses due not only to low rainfall, but mainly to the melting of the permafrost, forming important reservoirs of water.

1. Introduction

The Sierra de Famatina (SF), one of the main constituents of the morphostructural region known as Famatina System, is located in the north center of La Rioja Province, between 27° and 30° south latitude. The SF is characterized by mountain ranges that surpass 6000 masl, which are the highest of the continent out of the Andes Cordillera. The General Belgrano hill (6097 m) is, together with others lower ones (Overo Negro, El Overo, El Pelado hills, among others; Fig. 1), the highest elevation of the whole system. This feature, along with climatic and paleoclimatic issues, favored that not only in the present and the Quaternary, but mainly during cold times, much of its surface has been occupied by glaciers.

Currently, extreme climatic conditions allow the persistence of small patches of snow and ice at the highest altitudes, being the periglacial processes the most important, not only by their intensity, but also by extension (IANIGLA, 2017).

2. Geological setting

The tectonic style of the Famatina System responds to the interaction of the basement and the sedimentary cover, with high-angle thrusts that are strongly controlled by the structuring of the crystalline basement and scaling systems with vergence to the west. It is made up of a low-grade metasedimentary basement and an important Ordovician sedimentary and volcanic-sedimentary cover that allow its separation from the Sierras Pampeanas located eastward and westward. Simultaneously, a calc-alkaline magmatism was developed, and later, extensional tectonics of the Gondwana Cycle facilitated the intrusion of peralkaline leucogranites. During the Tertiary (Andean Cycle), riodacitic and dacitic intrusions gave rise to wide areas of hydrothermal alteration with diverse mineralization and strong lifting along inverse faults resulting in the current arrangement (Candiani et al., 2011). On this structural arrangement the action of the most recent geomorphologic processes gave the present landscape, which changed according to paleoclimatic changes and neotectonic movements.

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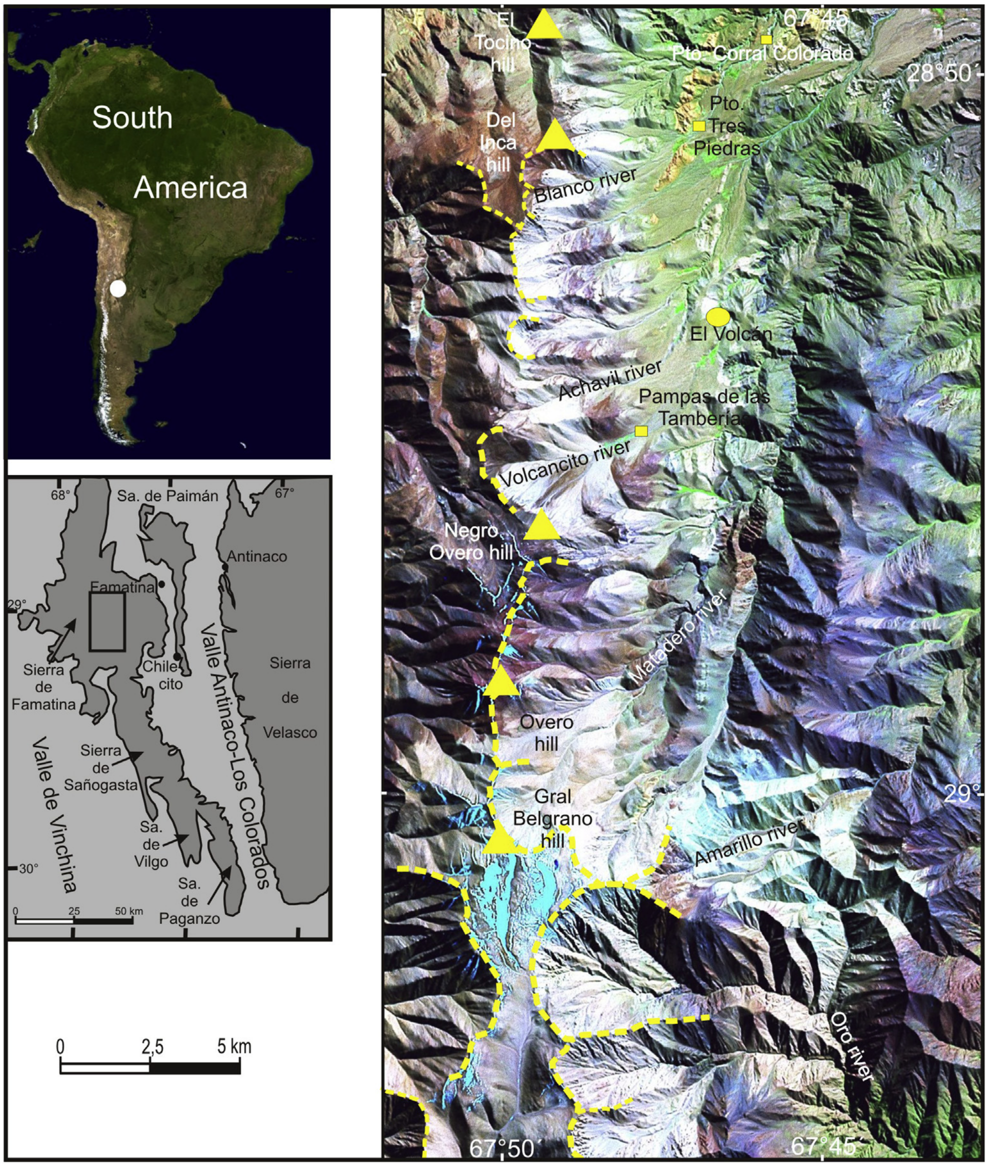

Fig. 1. Location map.

3. Background

Geomorphological aspects of the Famatina System have been little studied, except for general approaches to the types of processes, their intensity and chronology. Bodenbender (1916) was one of the first to refer to the glacial processes in the Famatina System. Although he briefly described these deposits as "moraines", he reported the existence of past glaciations in these mountains. Later, Turner (1971), Fauqué and Caminos (2006), and Candiani et al. (2011), mapped and briefly characterized these deposits within the area originally defined by Bodenbender, and limiting to General Belgrano hill, Pampa de las Tamberías and surrounding areas. Garleff and Stingl (1996) performed detailed studies on periglacial processes and suggested for 30,000 years BP, more humid conditions above 5800 masl which led to glacier formation, although more arid conditions during the Last Glacial Maximum (~18,000 years) would have not favored the formation of glaciers but the expansion of the periglacial area.

4. Description of the area and methodology

The Sierra de Famatina has the highest elevation of the whole System, with the General Belgrano (6097 masl), Overo (5930 masl), Overo Negro (5791 masl), and Tocino (4530 masl) as the main hills. These mountains are north-south aligned, forming the watershed that separates the drainage toward the Antinaco-Los Colorados valley eastward, and the Vinchina valley westward (Fig. 1). The major basins draining eastward, because of a watershed offset westward, correspond north to south to the rivers Blanco, Achavil, Amarillo, Oro and Miranda. The headwaters of these courses are located in the surroundings of these hills where the glacial, and current and past periglacial processes, are the most important, followed by mass movement and fluvial processes.

The north-south watershed is soft-shaped near the highest part, grading to more broken-shaped both southward and northward, being very acute in the northern sector. From this watershed arise similar secondary watersheds, whose shapes become smoother and eventually vanish because of glacial, periglacial and weathering processes produced both in space and time.

The study is focused on the headwaters of the Volcancito, Achavil and Blanco rivers, which drain towards the Antinaco-Los Colorados basin and in the vicinity of Puesto Tres Piedras (Fig. 1).

The first approaches on the characteristics of the study area were carried out with 1:200,000 and 1:100,000 topographic maps of the Geological and Mining Survey of Argentine (SEGEMAR) and the National Geographic Institute (IGN), a geological map at a scale of 1:250,000 (Fauqué and Caminos, 2006), geological maps 1:100,000 (Candiani et al., 2011), and satellite images (Landsat 8, Spot and QuickBird). The identified geomorphological traits were surveyed in the field in order to characterize their lithological composition, processes and geomorphological contexts, as well as their relationships with other morphologies. In the natural or anthropic sections, the lithological profiles were surveyed, recording textures, structures, color and lithological characteristics. Sediment and biogenic content were sampled to obtain numerical data, in the Laboratory of Radiocarbon (LATYR–CIG). Barometric GPS, Google Earth and topographic maps were used for the determination of topographic heights, controlling when possible with IGN points. The information acquired both in laboratory and field work, was joined and graphed, in order to obtain the distribution of the geomorphological traits that evidence the processes involved in their formation and the relationships among them.

5. Present climate

The province of La Rioja belongs to the arid diagonal of South America, characterized by a temperate and arid climate with very long summer and a permanent hydric deficit.

The rain is sporadic with alternation of dry and wet periods. Precipitations occur mainly in summer, being January the wettest month, while winter is very dry. On the other hand, precipitation decreases from east to west (300 mm).

According to the meteorological data published by the National Meteorological Service (SMN, 2016), in the period between 1941 and 1960 there were average temperatures of 24.7 °C for January and of 8.5 °C for June. Also, the mean annual temperature for the same time interval is 17.2 °C.

On the basis of most recent data (1991–2010), average temperature of January (summer) is 25.5 °C and of July (winter), 9.7 °C. The mean annual temperature is 18.5 °C.

Between 1941 and 1970, the absolute maximum temperatures recorded in the SMN (2016) exceeded 40 °C in summer, with the maximum (42.6 °C) recorded between 1941 and 1950. The absolute minimum ranged from −4.9 to −7.7 °C. The data for 1999–2010, yielded an absolute maximum temperature of 43.1 °C recorded on January 7, 2006, and an absolute minimum temperature of −7.7 °C for July 13, 2000, always referred to the Chilecito Station.

The wind frequency, both between 1941 and 1970, and 1991–2010, determined that the prevailing winds belong to the southern quadrant throughout the year (SMN, 2016).

In winter, snowfalls are common, mainly in the highest parts of the mountain system, where snow can last much of the year.

The region is characterized by strong continentality, low humidity, strong daily insolation, atmospheric transparency, seasonal rains (violent and torrential) and strong evaporation, as well as warm and dry winds. Locally, and although the diverse mountain systems produce important changes in the climatic conditions of the region, it corresponds, according to the classification of Köoppen (Peel et al., 2007), to a BWw climate, i.e., arid with summer concentration of the precipitation, less than 250 mm/year.

6. Geomorphology

The present structural arrangement of the Famatina System is due to the tectonic movements associated with the Andean Cycle (Ramos, 1999), from which the exogenous processes, and to a lesser extent the neotectonic, produced the geomorphological features observed today, corresponding mainly to glacial, periglacial and fluvial environments.

6.1. Glacial environment features

The main watershed, aligned north-south with the General Belgrano, Overo, Overo Negro and Tocino hills, among others, has an acute and sinuous morphology. Secondary watersheds similar in aspect emerge at both sides (Fig. 1). These divides represent serrated ridges (arêtes) limiting glacial cirques and troughs. Slopes are very steep (they surpass 50°) and are covered mainly by very sharprock fragments. The rock is exposed only in the watersheds, although structures and lithologic alternations can make it also appear on the flanks or the bottom of the valleys. The main watershed loses the morphology of arêtes in some sectors to form true "high pampas", such as in the vicinity of the General Belgrano and Overo Negro hills, where patches of ice and snow are currently concentrated, almost static (Taillant, 2012; IANIGLA, 2017).

Cirques are amphitheater-shaped depressions with very steep walls, partially occupied by gelifracts, rock glaciers or moraines. The troughs already described by Bodenbender (1916) are developed from the cirques, or emerge directly from the main watershed, with their typical U-shape, their slopes covered by mantles of regoliths and moraines, and their bottoms by fluvial deposits.

6.1.1. Moraines

The main moraine deposits are found in the headwaters of the Volcancito, Achavil and Blanco rivers (Bodenbender, 1916; Turner, 1971; Fauqué and Caminos, 2006; Candiani et al., 2011). From the headwaters of these valleys, moraines accompany different positions of the troughs, generally bottom troughs, such as those observed at the Pampas de la Tamberías and east of the El Pelado hill. In the vicinity of the Puesto Tres Piedras, on the Blanco river (Fig. 1), two levels of lateral moraines can be observed along 2.5 km at 3000 m height (Figs. 2 and 9). These lateral moraines, which are at both margins of the course, are formed by very heterogeneous materials, friable, matrix-supported, and their surfaces covered by blocks that may exceed 3 m long (Fig. 3). These blocks are strongly weathered; hence, without minor features of glacial erosion. The outcroppings are tens of meters thick, without pattern, with large sharp blocks within a fine matrix, together with smaller blocks that scarcely keep vertical exposures. The soil shows very little differentiation of horizons and is occupied by shrub vegetation that disappears with altitude.

Another exposure of till may be observed at the inner walls of El Volcán (Candiani et al., 2011), formed by a matrix-supported breccias, 50 m thick, with faulted blocks that reach one meter in diameter (Fig. 3A). These breccias have an important degree of consolidation, forming vertical walls along the whole circumference and in the channel that drains this structure, where it only displays a half cane in the base, product of the weathering in the zone of greatest humidity, with the consequent crumbling. All the water is indigenous to the structure, with similar discharges in summer and winter, as a consequence of the periglacial conditions of the landscape.

6.1.2. Glacifluvial plain

Downstream the Blanco River, near Puesto Corral Colorado, there is a flat surface, cut by the channel, composed of about 30 m of fluvial sediments, finely stratified, composed mainly of gravel, sand and silt with isolated angular blocks (Fig. 3B). These deposits correspond to the glacifluvial plain of the glacier body developed upstream, whose moraines are associated (Fig. 2).

In front of Puesto Tres Piedras there is a ravine 8 m deep, cutting sediments represented at the base by matrix-supported breccias (till), and matrix-supported roughly stratified conglomerates (fluvial), and at the upper 3 m by sand, silts and clays, finely laminated, and locally folded, red, white and black, with levels of high concentration of organic matter (Fig. 4). The dark layers, containing abundant peat-like organic matter, were dated in 470 ± 60 years BP (LP-3474) and would be associated with the Little Ice Age (Bradley et al., 2003), with

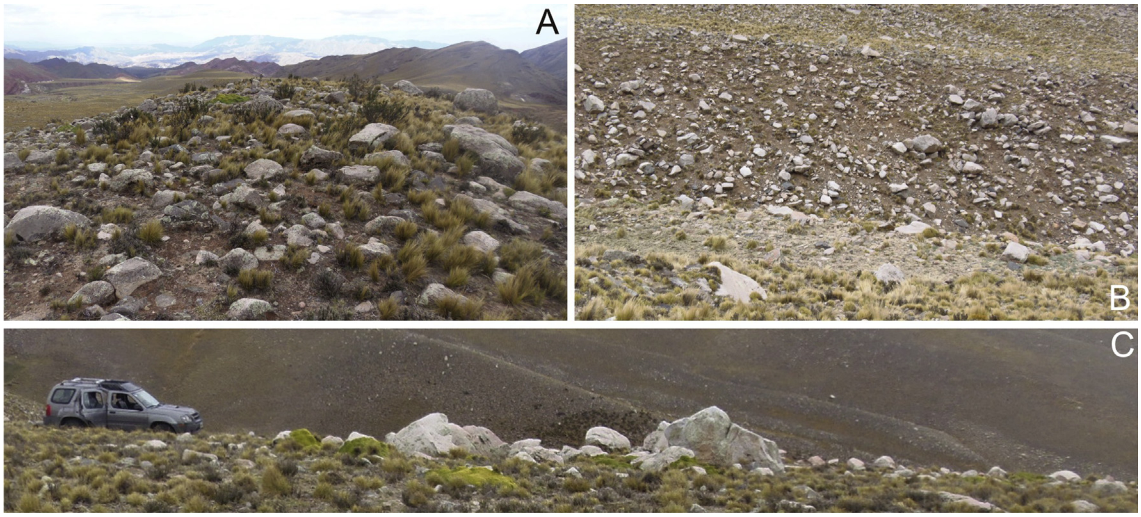

Fig. 2. Photographs of surface and exposures of lateral moraines in the vicinity of Tres Piedras (28°50′4″S/67°46′58″O) (A taken toward the NE and B taken toward the SO) and Volcancito (C) (28°53′8″S/67°46′46″O).

subsequent deformation due to periglacial processes. This sector is interpreted as a basin that could accommodate a small body of snow and ice during the last glaciation, remaining isolated from regional exogenous processes and evolving in a very local way.

6.2. *Periglacial features*

The term "periglacial" was used to describe the climatic and geomorphological conditions of peripheral areas to Pleistocene ice and glaciers (Losinski, 1912). Currently, this term refers to cold, non-glacial climate, ruled by non-glacial geomorphic processes, such as freezing and thawing cycles involving both the rocky material and the portion of the soil close to the surface, an essential aspect as a defining condition for the Andes Cordillera (Trombotto Liaudat, 2008).

The term "*debris glacier*" (Corte and Buk, 1976), also referred to as "rock glacier", corresponds to mesoforms of sedimentary accumulation composed of rocks and frozen debris that move downhill by plastic deformation and creeping permafrost (Corte, 1976; Giardino et al., 1987). The rock glaciers generally have a tongue or lobulated form in plan view and an irregular topography surface characterized by a succession of ridges and grooves, mainly transporting rock fragments generated by thermal cracking or by till glacier (Barsch, 1987, 1992; French, 2007).

Near General Belgrano and Overo Negro hills, 30 bodies were surveyed that may belong to debris glaciers or a form of rock glacier called *protalus lobes*. These bodies range in height from 4200 to 6090 masl (Taillant, 2012).

The largest rock glacier is east of General Belgrano hill, at the headwaters of the Matadero river, on the opposite slope of the mining complex La Mejicana. It belongs to cirques filling, limited by a sliding escarpment generated on detritic materials (Fig. 5). It is composed of heterogeneous materials, mostly fine gravels with scattered blocks. It has arched ridges and grooves, and small size scarps (50 cm), in which water outcrops in summer. Different lobes separate, merge and interfinger, resulting in a complex shape, producing flow processes and compressive stress (Haeberli, 1985), variations in the supply of detritus (Barsch, 1977), or differential movement of debris (Ives, 1940). The whole set, downstream conical in shape, ends in a permanent water course. A lobe of the debris glacier separates from the main body (Fig. 5B) and moves toward a road built by the miners, which is currently useless because of the fall of large rocks as a result of its movement.

The hydrological importance of debris glaciers and the periglacial environment has been studied by numerous authors in the Andes (Corte, 1976; Buk, 1983; Trombotto et al., 1999; Croce and Milana, 2002) since they are long-term water reservoirs. The active layers act as aquifers (Burger et al., 1999), and ice-rich permafrost can act as aquiclude, promoting surface runoff through the active layer. Despite being on average much smaller than glaciers, debris glaciers can be found in greater numbers and contain a volume of water that may even exceed that of glaciers (Brenning, 2003, 2005).

6.2.1. *Gelifluction lobes*

Most of the slopes of the main watersheds, lacking vegetation, have a continuous mantle of gelifracts, where lobes, approximately 30 m width, develop in the sense of the slope, and become elongated with increasing slope (Fig. 6A and B). The material is loose, heterometric and very angular (Fig. 6 C). Where the material is finer, there are channels in similar positions, in the direction of the slope, characterized by a central groove limited by lateral elevations, ending at the base of the

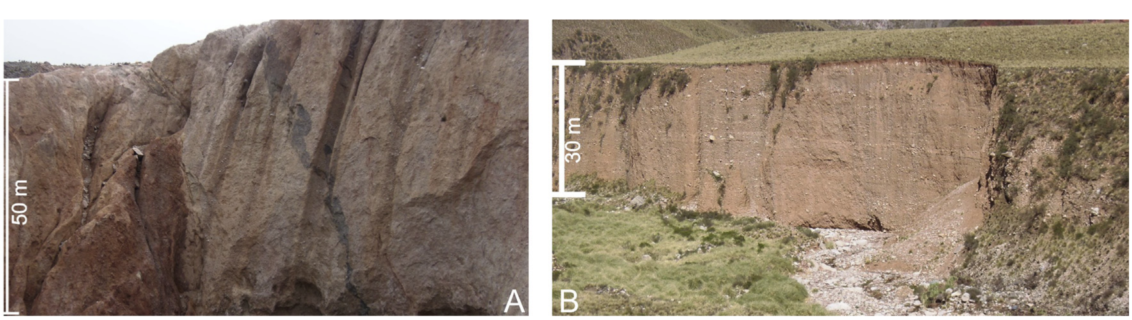

Fig. 3. A. Moraines exposed inside El Volcán (28°53′20″S/67°46′31″O). B. Fluvioglacial deposits of the Blanco river (28°49′33″S/67°45′52″O).

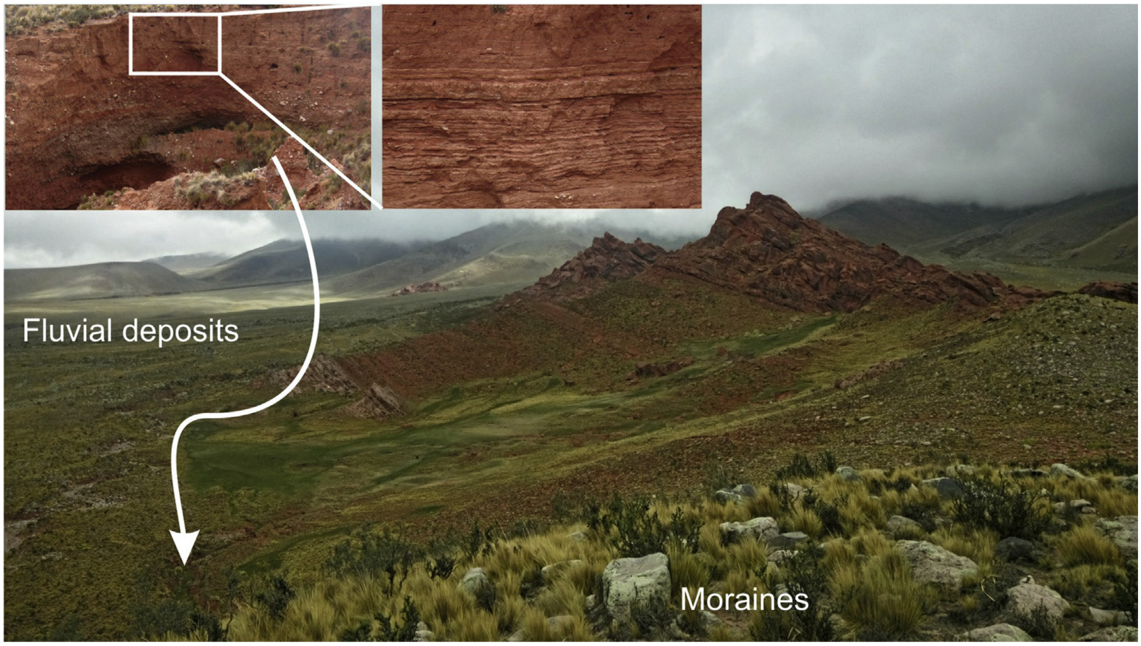

Fig. 4. Landscape and exposures of the glaci-fluvial-lacustrine deposit near Puesto Tres Piedras. (28°50′4″S/67°46′58″O). The photograph is taken toward the SSE.

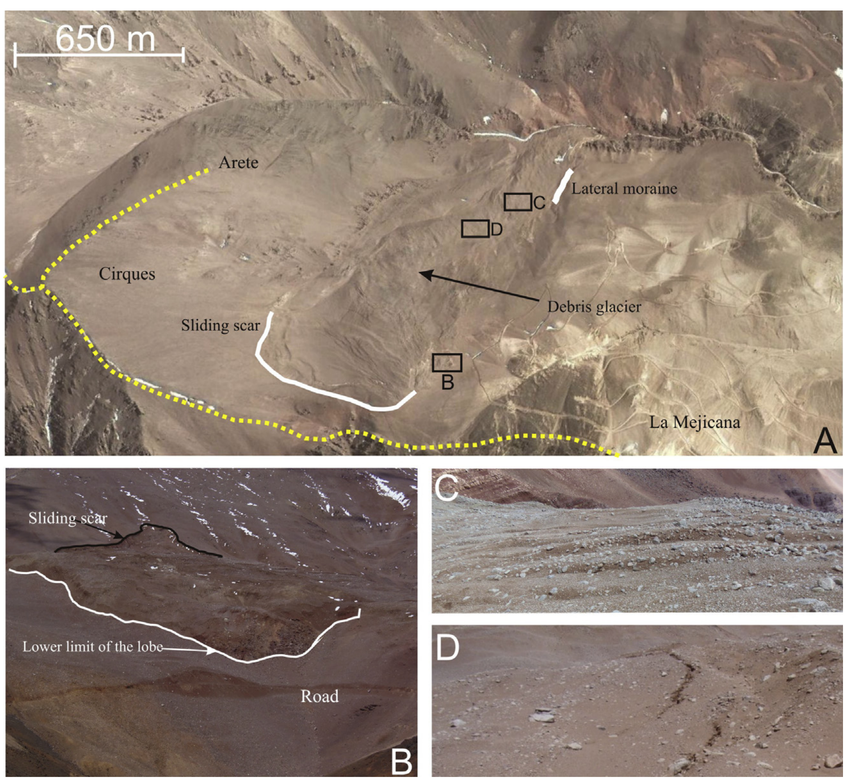

Fig. 5. A. Rock glacier at the headwaters of the Matadero river in a glacial cirque (29° 0′27.21″S/67°47′39.59″O). B. Rock glacier lobe detached from main debris glacier. C and D. Ridges, grooves and cracks of the rock glacier.

slope or in the middle of it, in an elongated lobe, most likely when water diminishes, either by infiltration or wetting of the material (Fig. 6 D). This process is related to intense precipitation or rapid melting of small accumulations of snow, and to a transition between channeled runoff and flow type mass removal.

6.2.2. Stepped soils

They are soils arranged in steps, forming banks on slopes of 3–20° inclination. Steps with a vegetated margin are called unsorted (Washburn, 1979) (Fig. 7 A). The origin of this process would be mainly related to the differential mass movement, very limited in both surface and depth. They are found on stable slopes, which favor the establishment of vegetation.

6.2.3. Earth hummocks

They are dome-like vegetated forms, 1–2 m of maximum diameter and around 50 cm high, with internal cryoturbations. They develop above the limit of growth of the trees and their origin seems to be

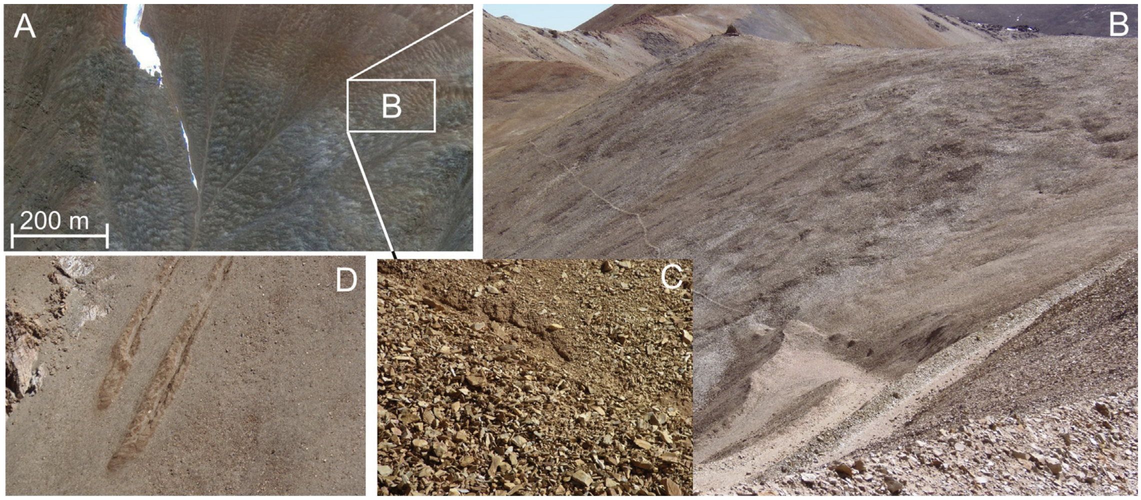

Fig. 6. Gelifluction lobes in the highest sectors of the system. This photograph is taken at the headwaters of the Matadero river (28°59′39.11″S/67°49′31.24″O).

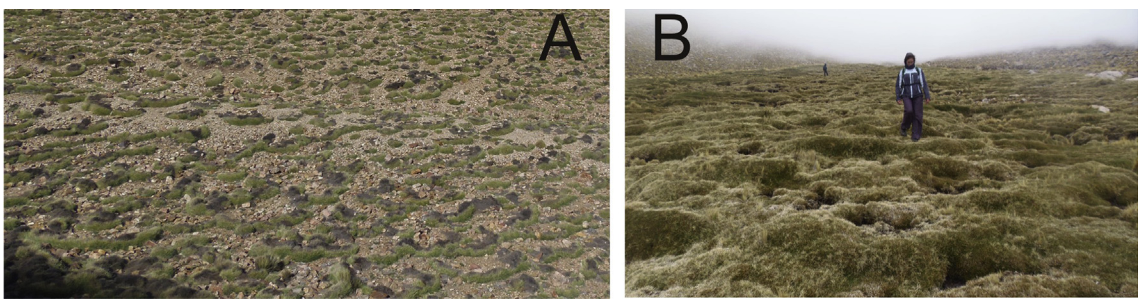

Fig. 7. A. Stepped soils developed in slopes (29° 0′14″S/67°44′21″O). B. Active earth hummocks in the headwaters of the Blanco river (28°51′23″S/67°48′27″O).

related to mass movements (Schunke and Zoltai, 1988). These morphologies are observed in specific places in the bottom or in the slopes of valleys (almost always in the southern wall), produced by the emergence of subsurface waters (Fig. 7 B). They are represented in the surface by patchy vegetation on low to moderate slopes, water saturated, composed of muddy-sandy to gravel materials, very dark, with clasts inside. Most of the year these are places of permanent waters, whereas in winter the outcropping and interstitial waters are frozen. Isolated morphologies of this type can be observed in almost every valley; in some cases they are non-functional, as the change in the direction of the runoff leads to desiccation.

6.3. Fluvial environments

The end of the glacial events generated fluvial deposits varied in development and characteristics, both morphological and sedimentological. Extensive detritic mantles of *braided* or *distributary* designs are observed occupying the bottom of valleys or troughs, which generate intramontane slopes (Fig. 8). According to the morphologies produced by current or past river action, the courses have different characteristics. Above 3000 m they are little steep-sided, draining transitorily on a mantle of fluvial debris, which was previously accumulated by gravitational, glacial or periglacial processes. Spring - summer snow melt and current seasonal storms generate transitory courses, whose headwater are glaciers and rock glaciers, with a narrow central channel bordered by levees; this set is elevated from the bottom of the valley, corresponding to debris flows. They can drain for several kilometers while the slope is sufficient, and then they disappear by infiltration downstream, traversing in many cases earth hummocks. Since they occupy large areas and low slopes, they develop alluvial plains of braided designs, most of which are stabilized by vegetation, being their genesis probably in the last deglaciation. From these sectors the courses deepen, digging the basement and giving rise to deep canyons, until reaching the Famatina piedmont where they finally leave their deposits.

Downstream the intramontane slopes the valleys are deeply carved in odd terraces. The divides of folded Neogene rocks underlying detritic

Fig. 8. Channel deposits and intramontane slopes.

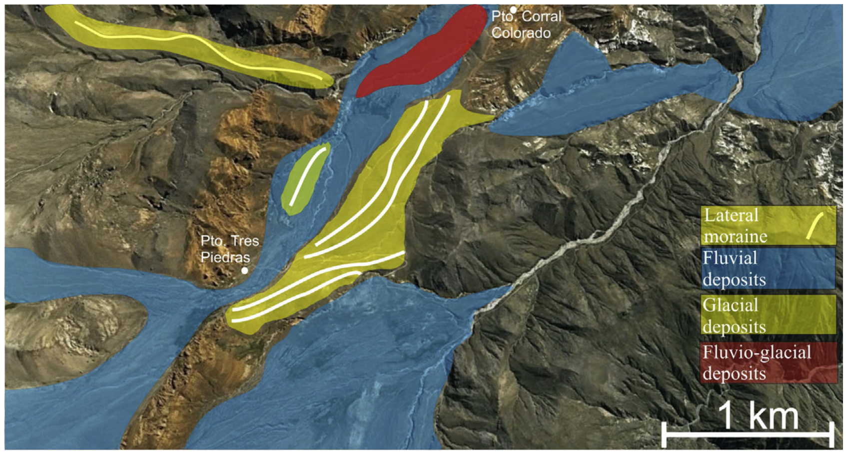

Fig. 9. Distribution of different deposits in the area of Puesto Tres Piedras.

mantles in angular unconformity represent covered pediments. This landscape evidences tectonic reactivations exposed by the numerous faults, generally inverse, observed in Quaternary deposits.

7. Discussion

Main and secondary hills and watersheds above 3500–4000 masl have soft morphologies produced by cryoplanation and glacial action interrupted by rocky outcrops. These watersheds and flanks of valleys are covered by an almost continuous sheet of debris produced by cryogenesis, blurring the original glacial forms such as troughs, horns, cirques and arêtes. In cirques and troughs different tills form in some cases clear moraine forms (surroundings of Puesto Tres Piedras, Cerro Tocino, Pampa de las Tamberías), although in others, they form directly the watershed of the valleys, as in El Volcán, which shows, in addition to its lithological attributes, different chronologies. Likewise, rock glaciers at the headwaters of cirques and troughs are developed from glacial drift, as well as weathered material. The age of these last drifts may correspond to the last glaciation (i.e., MIS2). Two other independent cold events could be interpreted assigning the moraines of Puesto Tres Piedras to the Middle Pleistocene and those of El Volcán, composed of more compacted and faulted materials, to the Lower to Middle Pleistocene. The deposits near Puesto Tres Piedras and Tocino hill are the lowest ones (3000 masl), and those at higher altitudes display greater development. Downstream the moraine front, associated with these deposits, there are fluvial deposits assigned to fluvioglacial plains (Fig. 9).

Hanging from the main headwaters, the rock glaciers, which represent the most extreme morphological expression of the mountain permafrost creeping (Haeberli, 1985; Trombotto, 1991; Brenning, 2005), are developed. These landscape features were used in the Andes to infer the altitudinal boundary of the discontinuous mountain permafrost (Barsch, 1977, 1978; Garleff, 1977; Corte, 1983; Brenning, 2005); this limit is 3500 m for the Cordillera Principal of Mendoza (Ahumada, 1990) and in the study area, would be from about 4000 m. The main headwaters (high pampas) host the scarce patches of ice and snow; from here, gelifluction lobes develop in a mantle-like way, stepped soils on the slopes, and debris glaciers and earth hummocks in headwaters of troughs, cirques and bottom of valleys. These features play an important role in the regulation of the water regime, since they supply an important amount of melting water, being very sensitive systems to climate change (Lowell, 2000; Oerlemans, 2005; Rupper et al., 2009).

8. Conclusions

- Although glacial events had already been mentioned in the Sierra de Famatina, they have been only briefly described. Depending on the lithological and geomorphological characteristics, three different tills could be recognized. The oldest is formed by deposits with no defined morphology and well compacted materials, which could correspond to the Lower to Middle Pleistocene. The second, with a good geomorphological definition (lateral moraines), loose materials and blocks of several meters in diameter on its surface, located above 3000 m, could correspond to the Middle Pleistocene. Whereas the youngest deposits, limited mainly to the heads of cirques and troughs, could be referred to the Late Pleistocene.
- Among the periglacial traces rock glaciers, earth hummocks and stepped soils, and gelifluction lobes, were recognized above 3500–4000 masl, that may be evidence of rework of moraine deposits or of gelifracts. Given the arid climatic conditions, this periglacial environment represents an excellent water reservoir.
- The fluvial action is currently restricted to the bottom of the valleys during storms. Undoubtedly during deglaciation it had a very important activity, which is represented by the extension of the intramontane piedmont environments with fans morphologies and braided plains. These morphologies are mainly located at the end of the troughs, from where they are digged in rocky valleys, until they end in piedmont environments outside the Famatina System. Tectonics, together with climatic changes, is a central component in the evolution of the landscape, resulting in the rearrangement of the different blocks and the constant tendency to the balance of erosion-accumulation, being piedmont levels (slopes and covered pediments) and fluvial terraces in very high position compared to the current base levels. These are attested in turn by faulting of very modern fluvial levels.

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References

Ahumada, A.L., 1990. Ambientes, Procesos y Formas Periglaciales o Geocriogénicas en Quebrada Benjamín Matienzo, Cordillera Principal, Mendoza. Rev. Asoc. Geol. Argent. 45 (1–2), 85–97.
Barsch, D., 1977. Alpiner Permafrost – ein Beitragzur Verbreitung, zum Charakter und zur ökologie am Beispiel der Schweizer Alpen. In: Poser, H. (Ed.), Formen, Formengesell shaftenund Untergrenzen in den heutigen periglazialen Höhenstufen der Hochgebirge Europas und Afrikas zwischen Artiks und Äquator, pp. 118–141 Göttingen.
Barsch, D., 1978. Active rockglaciers as indicators of discontinuous permafrost: an example from the Swiss Alps. In: 3rd International Conference on Permafrost. Natural Resources Center, Natural resources Council Canada, Ottawa, pp. 349–352.
Barsch, D., 1987. The problem of the ice-cored rock glacier. In: Giardino, J.R., Shroeder,

J.F., Vitek, J.D. (Eds.), Rock Glaciers. Allen & Unwin, London, pp. 45–53.
Barsch, D., 1992. Permafrost creep and rockglaciers. Permafr. Periglac. Process. 3, 175–188.
Bodenbender, G., 1916. El Nevado de Famatina. Bol. Real Acad. Córdoba 21, 100–182.
Bradley, R.S., Briffa, K.R., Cole, J.E., Hughes, M.K., Osborn, T.J., 2003. The climate of the last millennium. In: Alverson, K.D., Bradley, R.S., Pedersen, T.F. (Eds.), Paleoclimate, Global Change and the Future. Springer, Berlin, pp. 105–141.
Brenning, A., 2003. La importancia de los glaciares de escombros en los sistemas geomorfológico e hidrológico de la Cordillera de Santiago: fundamentos y primeros resultados. Rev. Geogr. Norte Gd. 30, 7–22.
Brenning, A., 2005. Geomorphological, hydrological and climatic significance of rock glaciers in the Andes of Central Chile (33–35º S). Permafr. Periglac. Process. 16, 231–240. http://dx.doi.org/10.1002/ppp.528.
Buk, E., 1983. Glaciares de escombros y su significación hidrológica. IANIGLA-CONICET, Argentina, pp. 22–35.
Burger, K.C., Degenhardt, J.J., Giardino, J.R., 1999. Engineering geomorphology of rock glaciers. Geomorphology 31, 93–132.
Candiani, J., Astini, R., Dávila, F., Collo, G., Ezpeleta, M., Alasino, P., Dahlquist, J., Carrizo, R., 2011. Hojas Geológicas 2969-18, Famatina Y 2969-24. Sañogasta, 1:100.000. Boletín 379. Instituto de Geología y Recursos Minerales, Buenos Aires.
Corte, A., 1976. Rock glaciers. Biul. Peryglac. 26, 175–197.
Corte, A.E., Buk, E., 1976. Hidrología glacionival del sector oriental de la Cordillera Frontal Cordón del Plata. Memoria Anual 1976. IANIGLA, CONICET, Mendoza. Argentina, pp. 63–72.
Corte, A.E., 1983. Geocriología. El frío en la Tierra. Ediciones Culturales de Mendoza, Mendoza, pp. 398.
Croce, F., Milana, J., 2002. Desarrollo de sistemas geocriogénicos en la zona del paso Agua Negra y su importancia en geología aplicada. XV Congreso Geológico Argentino, El Calafate.
Fauqué, L., Caminos, R., 2006. Hoja geológica 2969-II, Tinogasta, provincias de La Rioja, Catamarca y San Juan. vol. 276. Instituto de Geología y Recursos Minerales. Servicio Geológico Minero Argentino, Boletin, Buenos Aires, pp. 139.
French, H.M., 2007. The Periglacial Environment. J. Wiley & Sons, West Sussex, England, pp. 458.
Garleff, K., Stingl, H., 1996. Desarrollo del relieve durante el Cuaternario tardío en la región subtropical/árida semiárida de la alta cordillera Argentina. El Ejemplo de la sierra de Famatina. In: In: Aceñolaza, F.G., Miller, H., Toselli, A. (Eds.), Münchert Geologische Hefte, vol. 19. pp. 403–410 (Reihe A).
Garleff, K., 1977. Höhenstufen der argentinischen Anden in Cuyo, Patagonien und Feuerland. Göttinger Geographische Abhandlungen, 68, Göttingen 150 p.
Giardino, J., Shroeder Jr.J., Vitek, L. (Eds.), 1987. Rock Glaciers. Allen & Unwin, Winchester, Mass. USA 355p.
Haeberli, W., 1985. Creep of mountain permafrost: internal structure and flow of alpine rock glaciers. In Mitteilungen der Versuchsanstalt für Wasserbau. Hydrol. Glaziol. 77, 142.
IANIGLA, 2017. Inventario Nacional de Glaciares. Informe de la cuenca Varias de Velasco, provincia de La Rioja.
Ives, R.L., 1940. Rock glaciers in the Colorado front range. Bull. Geol. Soc. Am. Abstr. 50, 1913–1914.
Losinski, W. von, 1912. Die perigalziale fazies der mechanishen Verwitterung. Comptes Rendus. In: XI Congrés Internationale Géologie, Stockholm 1910, pp. 1039–1053.
Lowell, T.V., 2000. As climate changes, so do glaciers. Proc. Natl. Acad. Sci. 97 (4), 1351–1354.
Oerlemans, J., 2005. Extracting a climate signal from 169 glacier records. Science 308, 675–677.
Peel, M.C., Finlayson, B.L., Mcmahon, T.A., 2007. Updated world map of the Köppen-Geiger climate classification. Hydrol. Earth Syst. Sci. Discuss. 11 (5), 1633–1644 European Geosciences Union.
Ramos, V.A., 1999. Las provincias geológicas del Territorio Argentino. In: Argentina, Geología, Caminos, R. (Eds.), Subsecretaria de Minería de la Nación. Servicio Geológico Minero Argentino SEGEMAR. Instituto de Geología y Recursos Minerales, Buenos Aires, pp. 41–73 Anales 29, no 3.
Rupper, S., Roe, G., Gillespie, A., 2009. Spatial patterns of Holocene glacier advance and retreat in Central Asia. Quat. Res. 72 (3), 337–346.
Schunke, E., Zoltai, S.C., 1988. Earth hummocks (thufur). In: Clark, M.J. (Ed.), Advances in Periglacial Geomorphology. vol. 23. Wiley, Chichester, pp. 1–245.
Servicio Meteorológico Nacional, 2016. Estadísticas climatológicas de diferentes períodos (1941–1950, 1951-1960, 1961-1970). e informes internos, Buenos Aires.
Taillant, J.D., 2012. Los Glaciares y la Minería de la Provincia de La Rioja. Córdoba: Centro de Derechos Humanos y Ambiente (CEDHA) Serie Glaciares y Minería. 132 pp.
Trombotto Liaudat, D., 2008. Geocryology of southern south America. In: In: Rabassa, J. (Ed.), Late Cenozoic of Patagonia and Tierra del Fuego. Developments in Quaternary Sciences, vol. 11. pp. 255–268.
Trombotto, D., 1991. Untersuchungen zum periglazialen Formen schatzund zu periglazialen Sedimenten in der Lagunita del Plata, Mendoza, Argentinien, vol. 90 Heidelberger Geographische Arbeiten, Heidelberg, Heft 171 p.
Trombotto, D., Buk, E., Hernández, J., 1999. Rock glaciers in the southern central Andes (approx. 33ºS–34ºS), cordillera frontal, Mendoza, Argentina. In: Schäbitz, F., Liebricht, H. (Eds.), Beiträge zur quartären Landschaftsentwicklung Südamerikas, Festschrift zum 65.Geburtstag von Professor Dr. Karsten Garleff (Bamberger Geographische Schriften 19), pp. 145–173 Bamberg.
Turner, J.C.M., 1971. Descripción geológica de la Hoja 15d, Famatina (provincias de Catamarca y La Rioja), vol. 126 Dirección Nacional de Geología y Minería, Boletín, Buenos Aires 106 p.
Washburn, A.L., 1979. 406 pp.. Geocryology. A Survey of Periglacial Processes and Environments, vol. 117 Edward Arnold, London Issue 5.